Flicker Calculation Method for Variable Refresh Rate Display

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ABSTRACT

Variable refresh rate technology (hereinafter called VRR) has been widely used across different applications. In this paper, a new flicker measure based on IEC standardized method is proposed. Our simulation indicates that existing flicker measure shows unstable result measuring aperiodic waveform while the new flicker measure enhances robustness.

1 Introduction

Recently VRR or dynamic refresh rate has been developed and used in many applications. For gaming application with VRR technology, display's refresh rate dynamically varies over time in order to avoid screen tearing and stuttering induced by framerate inconsistency across display and GPU. When it comes to mobile application such as smartphones, smartwatches and tablets, the refresh rate switches to lower frequency to reduce power consumption, or to higher frequency to realize smoother motion.

Unlike conventional displays with static refresh rate, refresh rate of VRR displays could be different between different frame which might cause unwanted flicker artifact especially at the time that we switch the refresh rate. In order to characterize VRR flicker, it is necessary to capture the most visible flicker at the time of refresh rate switch.

There're many types of flicker calculation method developed and the one of the most widely used flicker calculation methods from industrial point of view is described in IEC 61747-30-1(1), which has been widely called JEITA method because the method was originated from Japanese standard JEITA (Hereinafter we call this method JEITA flicker method). JEITA flicker method was not intended to make predictions of flicker perception but characterize temporal luminance modulation. Regardless of that, JEITA flicker method has been used to predict flicker perceptions in display industry because it was well known

JEITA flicker method is not appropriate for such VRR displays because VRR has aperiodic complicated waveform and JEITA flicker method was basically designed for simple static refresh rate display, so it is only applicable when the display's waveform is periodic waveform. In addition, JEITA flicker method only takes a single frequency component into account. VRR displays could be a composite of multiple frequency components. Thus, we should take multiple frequency components into account with proper weighting factors using Temporal Contrast Sensitivity Function (hereinafter called TCSF).

For VRR applications, we propose a new flicker measure based on IEC standardized method (hereinafter referred to as VRR flicker measure). IEC 62341-6-3:2016(2) defines a flicker measure for OLED as flicker modulation amplitude. It is using a TCSF that is different than JEITA flicker method. The weighting factors from JEITA flicker method has constant weighting factors under 20Hz as shown in Fig.1, which is unrealistic case because we clearly have increased sensitivity of the human visual system in the range between 10Hz and 20Hz(3). On the other hand, the TCSF from IEC 62341-6-3:2017 corrigendum 1(4) behaves differently under 20Hz, which is consistent with many existing published papers. We would like to suggest that we use IEC 62341-6-3:2017's TCSF for flicker calculation method instead of the one of JEITA flicker method.

Furthermore, those JEITA and IEC 62341-6-3 use frequency domain analysis with Fourier transform technique. But according to CIE(5), frequency domain analysis should be used for periodic waveform, not for aperiodic waveform such as VRR applications. It is reasonable because Fourier transform technique assumes that a signal is periodic. Therefore, we invented time domain computation combined with IEC 62341-6-3:2017's TCSF to create better algorithm to characterize aperiodic flicker on VRR displays.

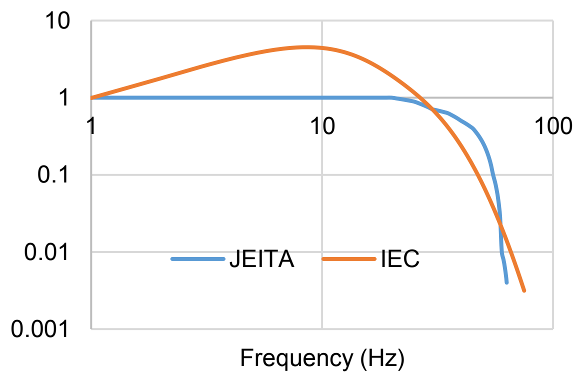


Fig. 1 TCSF from JEITA flicker method and IEC 62341-6-3:2017 corrigendum 1

2 Experiment

We conducted experiment and simulation to estimate flicker measure. Actual displays are often unstable over time and not appropriate for evaluation of flicker measure.

We used inhouse LED light source that reproduces intended waveform emission. Fig.2 shows the overview of the light source system. We combined the LED light source with a function generator and additional PCB so that we could use the digital waveform data as input and convert it into light emission output with same waveform shape. There's no standardized waveform test pattern for VRR displays yet so we designed the VRR-imitated waveform pattern ourselves like Fig. 3. As shown in Fig.3 (b), the waveform is made of two different components. The one imitates 30Hz refresh rate and the other 24Hz of refresh rate. This waveform pattern intends that we switch the refresh rate between 30Hz and 24Hz and observe luminance level shift at the timing of refresh rate switch. Adding to this, we used another test pattern that imitates normal static refresh rate display for comparison. Which doesn't switch refresh rate and continuously keeps the same waveform pattern over time. These waveform emissions were captured by display color analyzer that is capable of measuring luminance level at 3kHz sampling rate. From that captured waveform data, we calculated both JEITA flicker measure and VRR flicker measure, then compared both. The measurement was repeatedly conducted 10 times against the same waveform emission and each measurement sample takes 2 seconds sampling. Fig. 4 shows that two different randomly chosen waveform samples out of the 10 measured samples. As you can see, each sample corresponds to 2 seconds and includes a single event of refresh rate switch. However, the timing of refresh rate switch is different every time we took a measurement. Ideally speaking, measured flicker value should be the same whenever the refresh rate switch happens. In order to check the consistency, we intentionally shifted the timing of refresh rate switch within the 2 seconds sampling period.

The algorithm of JEITA flicker measure is shown in Fig.5 (a) and VRR flicker measure in Fig.5 (b). Apparently JEITA flicker measure is based on frequency-domain analysis and take the ratio of maximum AC and DC component in log scale. We need to multiply weighting factors based on the assumption that human visual system has different sensitivity at different frequency.

Originally in the IEC 62341-6-3 standard[2], TCSF is applied in frequency-domain in the same way as JEITA flicker method. As mentioned previously, for this type of aperiodic waveform, frequency-domain analysis doesn't work as Fourier transform technique is basically designed for periodic waveform. Therefore, in this paper, we use time-domain analysis instead to perform more robust and consistent measurement. More specifically, we convert TCSF into time-domain Impulse Response Function (Hereinafter IRF) and then take convolution of IRF and waveform in time-domain. The IRF was calculated by conducting Inverse Fourier Transform (IFFT) of the specific TCSF that is defined in the IEC 62341-6-3:2017 standard. In the IEC 62341-6-3:2017 standard, they never mention about phase information that is needed to conduct IFFT so we refer to the phase information described in Information Display Measurements Standard (IDMS) [6].

In this paper, we don't discuss predictions of flicker perception. The goal in this paper is to provide evidence that VRR flicker measure provides great robustness and consistency as well as capability of considering multiple frequency components with a single flicker measure when measuring VRR displays.

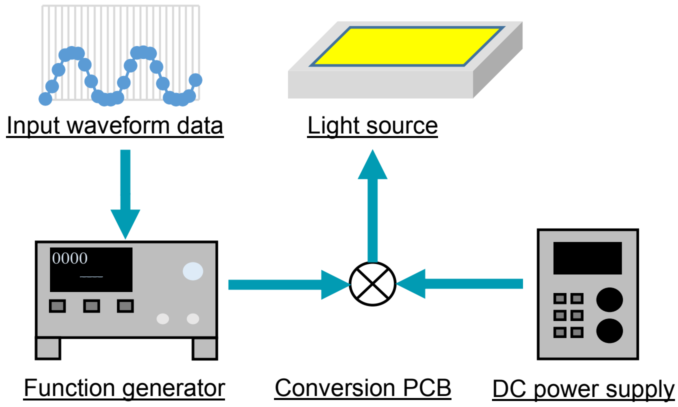
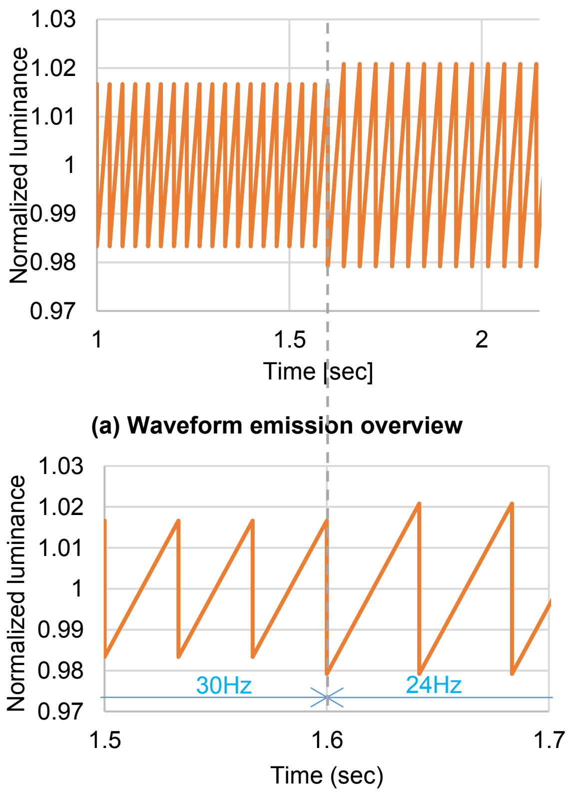


Fig. 2 Light source system configuration



(b) Waveform emission zoom-in
Fig. 3 VRR-imitated waveform emission

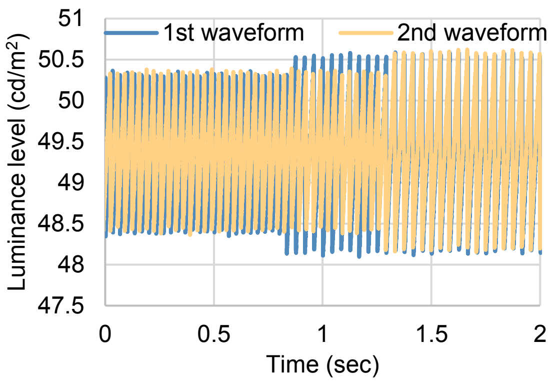
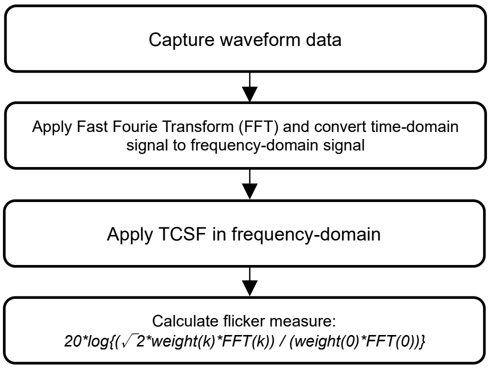
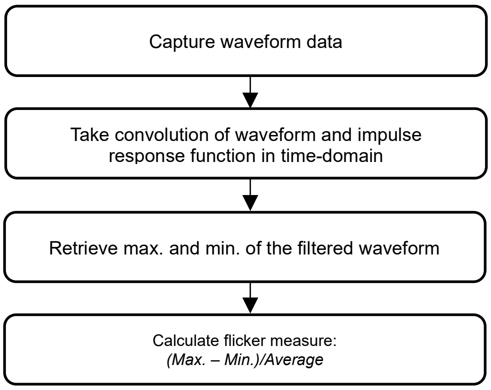


Fig. 4 Waveform emission samples that phase shift



(a) JEITA flicker method

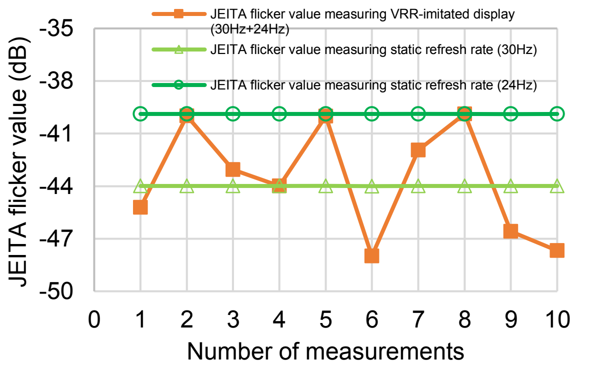


(b) Proposed VRR flicker measure

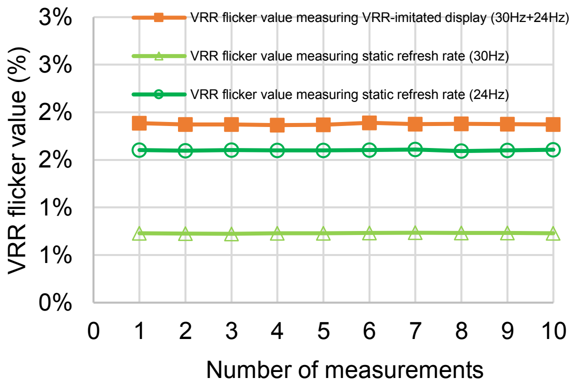
Fig. 5 Algorithm comparison of flicker calculation methods

3 Results

The results are shown in Fig.6. Fig.6 shows the comparison between JEITA flicker value and VRR flicker value measuring VRR-imitated waveform emission. We captured the same waveform emission 10 times continuously and see the variation in the value over 10 times measurements. Fig.6 (a) shows JEITA flicker value of VRR-imitated waveform as well as static frequency waveform. As you can see from the orange plot in the graph, JEITA flicker measure shows unstable and inconsistent result over multiple measurement. On the other hand, in the Fig.6 (b), the VRR flicker measure shows stable and consistent results across different measurement. In addition, we observed the difference in absolute value across two different measures.



(a) Continuously measured JEITA flicker value



(b) Measured VRR flicker value

Fig. 6 Comparison of JEITA flicker and VRR flicker value measuring VRR-imitated waveform

4 Discussion

The reason why that JEITA flicker value is unstable over different measurement is attributed to the frequency-domain analysis. JEITA flicker needs to apply Fourier transform to raw waveform emission. VRR-imitated waveform emission has refresh-rate switching point within the sampling window. Which means that some part of the waveform consists of 30Hz while the other part consists of 24Hz. If the sampling window is not synced with the waveform, the ratio of 24Hz and 30Hz could be different every time we take a measurement. In such case, we cannot accurately measure the amplitude of 24Hz that is included in the equation of JEITA flicker measure.

Apart from that, there's another problem with JEITA flicker measure. JEITA flicker measure only takes a single frequency component so in this case only 24Hz frequency component accounts for flicker measure. VRR displays apparently have multiple frequency components so JEITA flicker measure is not a proper method to characterize such flicker. Interaction between 24Hz and 30Hz at the time of refresh rate switch isn't considered at all. Thus, in this experiment, the maximum level of JEITA flicker measure was perfectly identical to the static frequency waveform. We expect that the most visible flicker appears at the time of refresh rate switch because of the interaction between 24Hz and 30Hz. Therefore, flicker value of VRR displays should be expected to be higher than static refresh rate display. But JEITA flicker method is not capable of measuring such interaction.

When we measured the VRR-imitated waveform emission with VRR flicker measure, then the result was more consistent as shown in Fig.6 (b). This is because we do the convolution in time-domain so that we could avoid the negative artifact caused by FFT.

One more benefit to this algorithm is that we could take the interaction between two different frequency components into account. As you can see from Fig.6 (b), the measured flicker value of VRR-imitated waveform is higher than the other of each static frequency waveform. This result imply that human visual system is prone to perceive more visible flicker at the time of switching the refresh rate than static frequency waveform.

5 Conclusions

In this paper, we proposed the new flicker measure that is based on IEC. This flicker measure surpassed existing JEITA flicker measure in terms of characterization of VRR displays.

References

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[2] IEC 62341-6-3 Ed.2: Organic light emitting diode (OLED) displays – Part 6-3: Measuring methods of image quality (2016).

[3] Michael E. Becker, "Flicker from Electronic Displays – Reconsidering the confusion", the Society of Information Display 50-1 (2019)

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[5] CIE. Visual Aspects of Time-Modulated Lighting Systems – Definitions and Measurement Models. Technical Note 006 (2016)

[6] International Committee for Display Metrology, Information Display Measurements Standard version 1.03 (2012)